Riparian landscapes

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> The Mississippi, the Ganges, and the Nile, those journeying atoms from the Rocky Mountains, the Himmaleh, and Mountains of the Moon, have a kind of personal importance in the annals of the world . . . Rivers must have been the guides which conducted the footsteps of the first travellers . . . They are the natural highways of all nations, not only levelling the ground and removing obstacles from the path of the traveller, quenching his thirst and bearing him on their bosoms, but conducting him through the most interesting scenery, the most populous portions of the globe, and where the animal and vegetable kingdoms attain their greatest perfection. *(Henry David Thoreau)*

Recent work in international ecology has focused attention on an area called 'Landscape Ecology'. Several recent symposia and books have pointed out a connection between the interaction of biotic and abiotic structures and functions and their spatial organization (Zonneveld 1990). In this book I will use some of the paradigms of landscape ecology to organize knowledge about riparian environments, and I will use that knowledge to assess those paradigms. While much of my approach will be toward ecological problems, I will also consider problems of a more broadly defined physical geography which are held in common with landscape ecology.

Disciplines

Landscape ecology

Landscape ecology has arisen from practical considerations of how ecological ideas could be applied in land management. The idea developed in Europe, where land management, including nature management, is intensive, and where the land has been clearly divided for centuries. Schreiber (1990) reviewed the development in Europe, giving much of the credit to Troll (e.g. 1939, 1968), and credits other German physical geographers in the 1960s (e.g. Neef 1963; Schmithusen 1963). Landscape ecology was introduced to North America in the 1980s (Forman and Godron 1981; cf. Forman 1990). In 1986, an American chapter of the International Association for Landscape Ecology was formed at the International Congress of Ecology. R.T.T. Forman pioneered this introduction with others (e.g. Risser *et al.* 1984; Naveh and Lieberman 1984), building on a sound reputation in ecosystems studies which he had applied to a whole region in New Jersey (Forman 1979). Forman and Godron's (1986) landmark work found a ready audience.

One reason for the ready audience in North America has not been given the attention that I believe that it deserves: the legacy of R.H. MacArthur. MacArthur (1972; MacArthur and Wilson 1967) developed the idea, in island biogeography, that space mattered. In island biogeography, distances, locations, stepping-stones, shapes, and areas have an effect on the sizes, dynamics, and organization of populations and communities. This work recognized that all habitats were islands of some degree and that spatial considerations applied in all places. These ideas were followed upon by many studies of isolated places. As a geographer trained in a spatial tradition (e.g. Abler *et al.* 1971) and intrigued by patterns on maps, I found that these studies served as a basis for a focus on spatial pattern and process. These studies often found that the simple relationships of area and isolation with immigration and extinction rates were complicated by various other environmental and spatial factors. In particular, early efforts to use the principles of island biogeography to address the design of nature reserves were quickly seen to have limitations (e.g. Simberloff and Abele 1976). These applied problems for real places demanded a more complex approach to the spatial aspects of ecology.

Landscape ecology is that approach, because it provides a framework and a sense of direction for the unformed ideas on how and why space mattered. Traditional biogeography sought to explain spatial patterns, with some reference to spatial processes. It did not, however, consider the dialectical nature of spatial pattern and process. Core concepts of landscape ecology, such as the mosaic controlling the flux of energy, matter, and information, are new developments that distinguish it from biogeography.

Physical geography

In essence, landscape ecology in the broad sense is the mostly abandoned core of physical geography, i.e. the spatially mediated interaction of environmental processes that creates the distributions of climates, life, and landforms on earth. Orme (1980), in reviewing the status of physical geography as part of a series published in *The Professional Geographer*, noted that in the early twentieth century physical geography consisted of efforts to classify and synthesize environmental processes of places or regions, but that in recent decades physical geography had been seen as an introduction to advanced study in the more specialized fields of climatology, geomorphology, etc. Physical geographers have been waiting for a unifying theme. Although the systems paradigm as presented by Chorley and Kennedy (1971) was meant to unify divergent interests in physical geography, the development of detailed systems analyses or systems related studies within separate areas became the dominant method of research.

Orme (1980) argued that in order for physical geography to be viable it should be definable. He wrote:

> But the subtle combination of subject matter and methodology does seem to create, in a societal context, a unique and definable role for physical geography, namely as a spatial and temporal explanation of natural phenomena at or near the earth's surface, with particular emphasis on the interrelationships among phenomena and between these and society.

The other three papers in the series in *The Professional Geographer* were specifically on biogeography (or ecological geography) (Vale and Parker 1980), climatology (Mather *et al.* 1980), and geomorphology (Graf *et al.* 1980). These works each stressed a unique role that physical geographers could make in their respective areas. Two themes are common: a spatial approach, expressed as environmental systems with topological and topographic relationships; and the interaction of people and environment. These two themes are held in common with landscape ecology. Because their research is better appreciated and recognized in allied disciplines rather than in geography itself, physical geographers had become increasingly specialized in these three areas, and the relationships among them had been disregarded. The central theme had been lost.

Landscape ecology, in part because it arrived in America with a developed tradition and recognition, has been readily accepted as a unifying theme by ecological geographers. In a discussion of the relationships among the three fields at a panel session during the Association of American Geographers annual meeting in 1987, the distance was obvious. The suggestion that landscape ecology may provide a way to rediscover the lost core was not met with enthusiasm by those in climatology or geomorphology, where it has yet to make an impact. Landscape ecology remains an ecological discipline. Landscape ecologists will continue to benefit from understanding the effects of the geomorphological development of a landscape and the climatological processes at landscape scale on the biota, but the flow of information in the other direction will take time. Geomorphologists and climatologists are beginning to acknowledge the importance of the biota for their concerns: two books, titled *Biogeomorphology* (Viles 1988) and *Vegetation and Erosion* (Thornes 1990), show the influence, and climatologists are beginning to recognize that the regional feedbacks from the biota and soil are critical to understanding regional and global climate. The development of geographic information systems has provided a tool by which data and models in the three areas that include spatial variation can be reconciled. This avenue for the future will be considered in the context of riparian environments.

The role of history

Debates have arisen in ecology over the successes and potential of reductionistic and holistic approaches to the field. No immediate resolution is in sight. It is worthwhile, however, to consider some aspects of our ontology and epistemology as we consider landscapes. In geography, this debate was once considered as a dichotomy between idiographic and nomothetic study. An idiographic approach considered every place to be unique and the description of this uniqueness to be a goal of study (e.g. Hartshorne 1939). The nomothetic approach, as the word implies, sought general laws that explained processes in many places (e.g. Harvey 1969). In geography this dichotomy was voiced by those who upheld the old tradition of regional geography and those who, in the 1950s and 1960s, led the quantitative revolution into thematic geography and especially spatial analysis. Physical geography, while moving directly into the nomothetic path, became so involved with process that the importance of either spatial relationships or place was absent from most actual research although acknowledged in theory (cf. Gregory 1985).

In ecology the distinction between idiographic and nomothetic approaches has been blurred, and in fact confounded. A major distinction has been made between what have been characterized as mere description and functional study. In fact it has been the population and community ecologists concerned with the processes of evolution who have worked in the nomothetic tradition by deriving hypotheses from theory and testing them with observations about the structure of populations and communities. Systems ecologists, on the other hand, have produced elaborate descriptions of the functions of ecosystems, but they have not, until recently, engaged in nomothetic science. Although their descriptions shared methodology and vocabulary, they did not propose or test theory.

Landscape ecology today draws from both of these traditions in the philosophy of science. Much of the emphasis has been on the nomothetic tradition. Forman and Godron (1986) cited many of the works regarded in geography as its foundations as a spatial science. But landscapes are in a sense unique. No two landscapes are the same, so that replication of units for study is impossible. Moreover, the role of history in the development of landscape pattern and process is overwhelming; no two landscapes have had the same history, and much of the history is unknowable. Decamps and Fortune (1991), while explaining the needs for sensible long-term research designs for riparian landscapes, emphasized that knowledge of the history of the landscape is critical to understanding its processes. In this situation, it is necessary to reevaluate the feasibility of a single or single-minded attempt at understanding. More recently in geography the debate between idiographic and nomothetic approaches has been reformulated and restated as a debate on the importance of place and space in the context of a contrast between logical positivism (sometimes as a strawman) or its replacement, realism or critical rationalism, and historical materialism. Suffice for now to say that at larger spatial scales a holistic approach seems needed and history limits the application of replicated reductionist methods.

Landscape reproduction

Landscape ecology is based on the hypothesis that the interactions among biotic and abiotic components of the landscape are spatially mediated. Not only are the flows of energy, material or species from place to place affected by the locations of the places in the landscape, but these flows then determine the interactions among energy, material and species. In ecosystem models, the processing of energy by species, for example, depends on the population size and available materials (e.g. nutrients for metabolism). Landscape ecology identifies how the availability of energy, material, and populations will be affected by their location, but exactly how these ideas might be operationalized, and hypotheses derived and tested, in real landscapes has not been explained.

My interpretation of the central theme of landscape ecology is that spatial structure controls the processes that continuously reproduce that structure. This continuous reproduction can be expressed as a dialectical development, and in some cases the difference between the process and the structure will need to be defined carefully. This concept of landscape reproduction needs to be considered in terms of actual rates of change and differences in the time scales of changes. This dynamic landscape development can be seen in terms of the feedbacks among processes which are affected by their locations or configurations in space. Not only the overall heterogeneity of landscape elements, but also their specific topology, affects the flows of nutrients, energy, and species on the landscape.

The dialectical concept implies a continuous relationship, while feedbacks imply discrete time steps. This difference is in part due to the modeling techniques applied in ecology wherein discrete time intervals often are specified for given processes. The best example of this is in the introduction of generation times in population models. Continuous models using differential equations in fact behave differently from discrete models using difference equations. In a landscape, some processes will operate at distinct annual cycles, while others will be continuous. Some may even have longer discrete periods. None the less, we can consider that landscapes are reproduced. While it may be too glib to use an organismic analogy, we could consider that as landscapes reproduce, they also evolve as the reproductive process includes variations in spatial pattern that are either more or less successful in a given environment.

When feedbacks are thought to operate, lag times must also be considered. Lag times in the effect of a feedback mechanism lead to nonequilibrium conditions (Malanson *et al.* 1992). Disequilibrium may be a fundamental component of ecological systems (DeAngelis and Waterhouse 1987). Landscape ecology is a particularly appropriate approach to the study of nonequilibrium systems because it takes into account the relations among the several processes of physical geography, and because nonequilibrium environments have distinct relations between hydrology, geomorphology, and ecology (Butler and Malanson 1990; Malanson and Butler 1990; Kupfer and Malanson 1992a). Moreover, landscape ecology focuses on one of the specific components of time lags: spatial separation.

Riparian landscapes for landscape ecology

Forman and Godron (1986) spent considerable effort on defining terms in landscape ecology. While some (e.g. isodiametric, i.e. circular), are unwieldy, most are useful. Most of the terms that they used are standard English and are used in ways that are not contradictory. In an area that is new, or at least unfamiliar to many, beginning with a common vocabulary is helpful, and Forman and Godron (1986) have served us well in this regard. These general definitions will be used here, and their definitions repeated if necessary.

A central problem for landscape ecology has been the definition of the smallest unit of study that makes up a landscape (as individuals clearly make up a population). Forman and Godron (1986) identified landscapes as made up of 'landscape elements' which in turn are made up of tesserae. They noted that how finely an area is divided, and thus what are the most homogeneous units and what groups they form, are not exact and may best be communicated by example. They used the example of an agricultural area. Elements are fields, farmyards, woods, and roads. Tesserae are the smallest homogeneous units visible, e.g. individual corn fields or woodlots. For riparian areas, the example is not so clear because of the continuity of the river, and in some cases the riparian vegetation, over long distances. In general, landscape elements in the riparian zone will include distinct vegetation types, wetlands, and other land-use categories. Tesserae, which I will discuss in terms of the internal structure of riparian zones, would be levees, abandoned channels, and their less distinct forms as ridges and swales within a floodplain forest. While differences may exist in the identification of elements in a real landscape, the concept is clear enough for the general discussion which follows. The title of this book, *Riparian Landscapes*, should not be interpreted to mean that a narrow river corridor is a landscape in and of itself, but rather that the riparian zone is a functionally dominant feature which contains and connects elements.

In a landscape which is made up of a number of ecosystems, the flows of energy, matter, and species are determined to some extent by the spatial configuration of the elements. Forman and Godron (1986) identified seven principles of landscape ecology which directly address these relationships. Being hypotheses or principles under development, some of them seem tautological, depending upon and deriving from the definition of landscape elements. The general idea is that landscapes are made up of several elements, and that the degree of heterogeneity, and thus the size of elements and edges, affects the interaction, or flows of energy, material, and species, among the elements. The heterogeneity also affects the way in which landscapes respond to disturbance through affecting flows and thus resistance and recovery.

The seven principles are:

Landscapes differ structurally in the distribution of species, energy and materials, and therefore differ functionally in the flows of species, energy, and materials among the elements.

Landscape heterogeneity decreases interiors, increases edges, and enhances species richness.

The changes in the distributions of species are controlled by landscape heterogeneity, which is in part defined by these distributions.

Nutrient flows in the landscape increase with disturbance.

Flows of energy and biomass across boundaries increases with heterogeneity (i.e. the number of boundaries).

The intermediate disturbance hypothesis applies to landscape heterogeneity as well as to species diversity.

Landscapes will develop either physical system stability, resilience, or resistance to disturbance.

While ecosystem studies have focused on such flows and interactions, they have missed the importance of spatial organization because they have looked within landscape elements or tesserae rather than among them. Even within landscape elements the importance of spatial location has often been generalized. Huston *et al.* (1988) have shown that identification of the location of individual trees in a small forest area will produce different results in a model of forest dynamics in comparison with spatial averaging, but most models are spatially averaged. Ecosystem concepts have treated the location of a given ecosystem in a landscape as its boundary conditions, and have proceeded to model the interactions with the inputs from and outputs to surrounding landscape elements as given. This approach, as pointed out by many workers in landscape ecology and biogeography, limits the explanatory power of the ecosystem paradigm. In two other fields closely associated with riparian studies, hydrology and geomorphology, spatially explicit models are more common.

Forman and Godron (1981, 1986) defined three major aspects of landscape structure: patches, corridors, and matrix. Patches are distinct landscape elements surrounded by others. Patches may be distinguished by their origin, size, and shape. Corridors are narrow landscape elements, differing from the surrounding elements. Like patches, they may be distinguished by origin, and size takes on characteristics of width, and shape takes on characteristics of sinuosity. The matrix is simply the dominant element in a landscape, and Forman and Godron (1986) give three criteria for distinguishing a matrix, which are inverse in their order of importance relative to their ease of definition: the largest area, the greatest connectivity, and the most control over dynamics. The overall pattern of patches and corridors within a matrix of a landscape may include networks in which patch number and configuration, corridor connectivity, breaks and nodes, boundary shapes, and overall heterogeneity operate to affect the flows of energy, matter, and species and their interactions. These ideas will be examined relative to riparian landscapes.

Riparian environments have received considerable attention from both ecologists and fluvial geomorphologists, but this work has not been given a unified conceptual framework. Here I define *riparian* in the broader ecological sense of the word, rather than the more restrictive sense of within the actual banks of the river (as preferred by C.R. Hupp, personal communication). In the broader sense, *riparian* includes the ecosystems adjacent to the river (this usage is long standing, as evidenced by the *Oxford English Dictionary*'s example for *riparial*). To try to use *floodplain* would be misleading because the riparian zone includes narrow strips along downcutting rivers, islands, and channel landforms as well as extensive floodplains. From the perspective of the ecologist, the dynamic processes of erosion, deposition, and water flow are considered as impacts upon the biota, and little attention as been paid to the reverse effects and essentially none to how the location of the ecosystem under study is important. Fluvial geomorphologists have considered the feedback between vegetation development and the processes of water and sediment movement, but here too the studies are specific to individual sites and little locational context has been considered. Decamps and Naiman (1989) presented an outline of the landscape level concerns for riparian ecology, and Naiman and Decamps (1990) presented a group of papers that go far in addressing some of these concerns, but feedbacks and the effect of space on the expression of environment in place still need investigation. In that book, Risser (1990) identified the importance of riparian ecotones for consideration of key current environmental issues, and noted that they can be a useful locus for testing ecological ideas. Gregory *et al.* (1991) have also noted the unique and important role of riparian ecosystems in a landscape setting. They specifically cited the linear spatial configuration and its role in increasing the interaction of the riparian zone with surrounding ecosystems.

Landscape ecology can provide a unifying concept to the diverse interests in the structure and dynamics of plant and animal communities, the trapping of sediments and nutrients eroded from agricultural fields, the alteration of flood hydrographs, and the development of landforms. Riparian environments provide a place where the hypotheses of landscape ecology can be operationalized and tested. Whereas Forman and Godron (1986) provided a framework for describing and classifying the spatial relations in a landscape, in the riparian environment the spatial relations are clarified. Their concept of corridor is critical here as a starting point (cf. Forman 1983). They note that a number of measures might be applied to a corridor: breaks or connectivity, variations in width, nodes or intersections, all of which combine to determine another of their points, the network. Because of breaks in the corridor, ideas applying to patches also must be considered: their size, shape, number, and configuration. The origin of the corridor landscape elements is also important. Landscape ecology also focuses on how the pattens affect the processes, particularly in relation to the control of flows of energy, matter, and species among landscape elements. Such flows are integral; the major ones well known in riparian areas, and the spatial structure of riparian areas, will need to be considered in respect of their functions as conduits and as barriers to these flows.

The aim of this book is to conceptualize the diverse work done on riparian environments, particularly in plant ecology, but extending into geomorphology, hydrology, and agricultural economics, in terms of landscape ecology and physical geography. Much of Chapters 4, 5, and 6 are in the nature of a review from this viewpoint. The interactions among the ecological, geomorphological, and hydrological factors that make up the riparian landscape are highlighted by examining how computer simulation models can be linked together using geographic information systems in order to provide a basis for testing hypotheses about the role of space. Specific dynamic models that emphasize the temporal aspects of one factor in one place are presented as components of a framework that allows the study of the interaction of components through time in diverse spatial conditions. Different spatial scales of focus are discussed. The implications of this approach for landscape ecology, for physical geography, and for the practical application of these concepts to land management are considered.

Conclusions

Landscape ecology is an approach to the study of the environment that emphasizes complex spatial relations. The relative locations of phenomena, their overall arrangement in a mosaic, and the types of boundaries between them, become the priorities of study. Spatial arrangements are not necessarily reducible to general rules, however: the history of individual places makes each unique. A landscape is continuously reproduced, as processes create patterns which in turn control the processes. Riparian environments are well suited for the elucidation of principles of landscape ecology: their ecology has been studied, their spatial characteristics are relatively clear, and they are found everywhere. This book explores how riparian environments can be seen in terms of landscape ecology.